

Fresnel Lens Gamma Ray Telescope

Flight Dynamics



Steven Cooley
Greg Marr
Charles Petruzzo
Scott Starin
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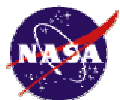


Flight Dynamics Topics

◆ Summary

- PI-proposed mission orbit description
- Formation initialization
- Formation station-keeping
- Formation re-orientation to next target
- Future work

◆ Detailed Information

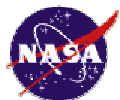




PI-Proposed Mission Orbit Description

♦ Desired Characteristics

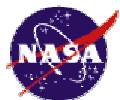
- Two S/C in formation, 10^6 km apart
- Maintain inertial orientation of SC-to-SC line for 2 week observation
- One SC follows a circular, heliocentric orbit
- Other SC follows a shifted, circular, heliocentric trajectory with orbit plane parallel to the plane of the first SC
 - Center of shifted trajectory lies on the Sun-target line 10^6 km from Sun





Driving Requirements

- Time allocated for reorienting the SC-to-SC line
- SC-to-SC line remains inertially fixed during observation
- Orbit control and knowledge requirements are not addressed in this analysis





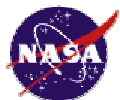
Formation Initialization

♦ One LV with a C3 of $0.4 \text{ km}^2/\text{s}^2$

- Needed to put the trajectories beyond Earth's sphere of influence (SOI is $\sim 10^6 \text{ km}$) Relatively Quickly

♦ One SC is maneuvered to the shifted orbit having origin 10^6 km away from the other's origin

- Two (High Thrust) Burn Option requires $\sim 370 \text{ m/s}$ total ΔV (two impulsive maneuvers, 3 months apart)
- Low-thrust Option requires further analysis and could require more than twice the High Thrust total ΔV . (Analyze Initialization Duration vs. Thrust Levels Required.)





Formation Station-Keeping

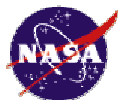
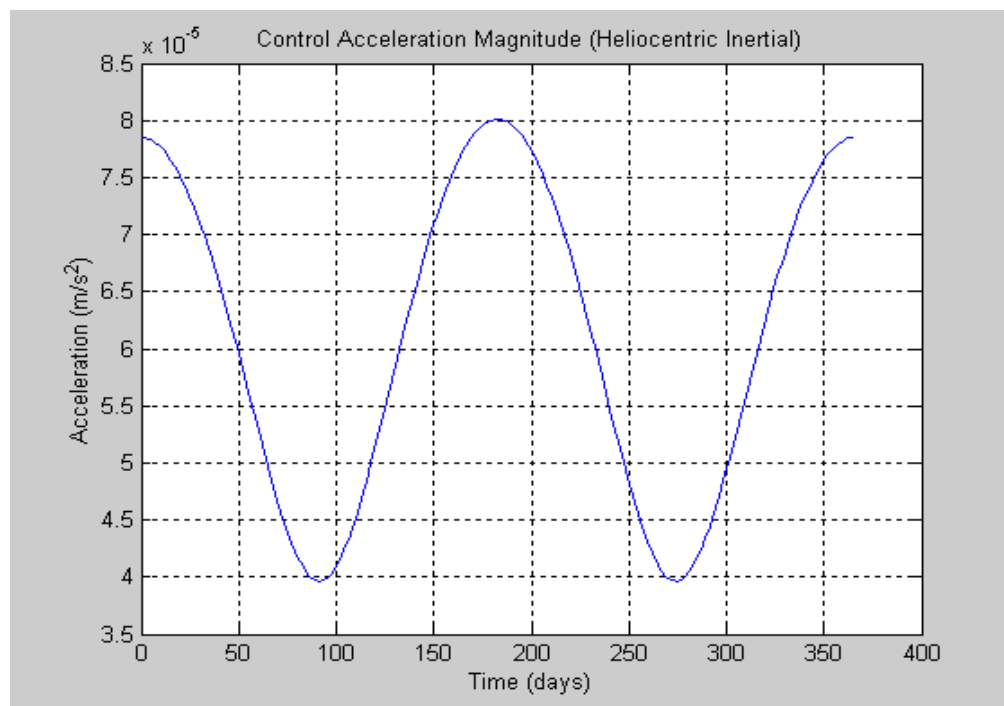
- ◆ Apply control accelerations continuously to maintain the inertial orientation of the SC-to-SC line

- ~50 m/s per week, max
- Only Solar Gravity Modeled

- ◆ Maximum control accelerations are needed when the trajectories are coplanar (it's counter-intuitive)

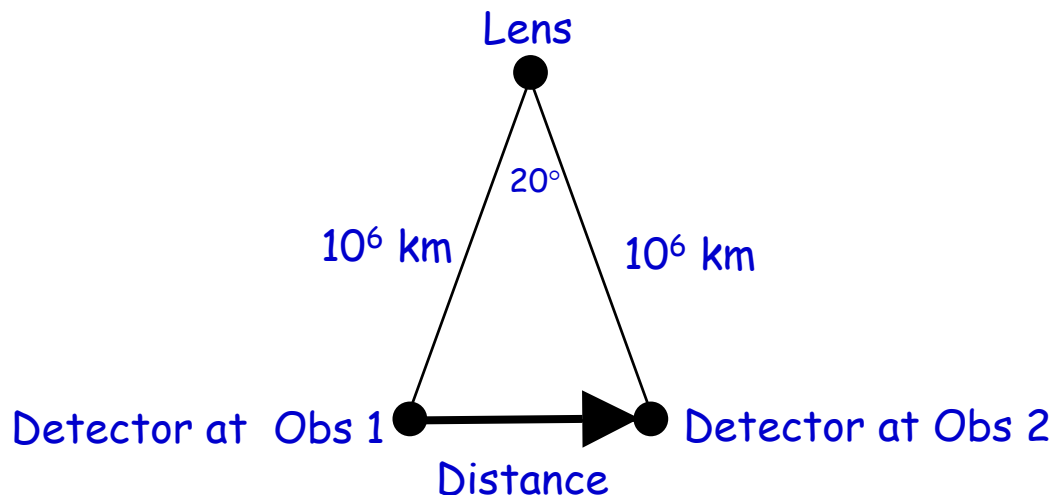
- 4×10^{-5} to $8 \times 10^{-5} \text{ m/s}^2$
- 40 to 80 milli-newton thrust for a 1000 kg SC

Control acceleration magnitude
-vs-
time since station-keeping starts

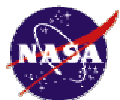




Formation Re-Orientation Free Space Analysis (1/3)



- ◆ Preliminary results: for “small” reorientation times (< 3 weeks), solar gravity has “small” effect on ΔV costs
- ◆ Free space analysis (ie, gravity free) is a reasonable approximation for small reorientation times





Formation Re-Orientation Free Space Analysis (2/3)

◆ Impulsive Burn Analysis

- One burn after obs 1 initiates translation of detector to the obs 2 location
 - Magnitude: $\Delta V_{\text{Impulse}} = \text{distance} / \text{reorientation time}$
- Equal but opposite burn stops translation when obs 2 location is reached
- Total $\Delta V = 2 * \Delta V_{\text{Impulse}}$

◆ Continuous Thrust Analysis

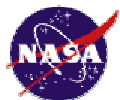
- Acceleration is constant toward obs2 location for first half of the time
- Acceleration is of the same magnitude, but reversed for the remaining time
- Total $\Delta V \text{ (m/s)} = 4 * \Delta V_{\text{impulse}}$
- Acceleration = $4 * \Delta V_{\text{impulse}} / \text{reorientation time}$





Formation Re-Orientation Free Space Analysis (3/3)

	1 Week Impulsive	1 Week Continuous	3 Week Impulsive	3 Week Continuous
Total ΔV (m/s)	1150	2300	383	766
Acceleration (m/s ²)	N/A	3.8 e-3	N/A	0.42 e-3
Thrust (1000 kg SC) (N)	N/A	3.8	N/A	0.42

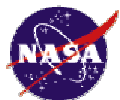




Formation Re-Orientation Lambert Problem (ie, gravity present)

- ♦ Calculate ΔV Needed to Move (20°) From Observation 1 to Observation 2 Under Solar Gravity ONLY
- ♦ Target Phase Angle of Shifted (Controlled) Orbit Chosen to Equal Phase Angle of Non-Shifted (Free-Flying) Orbit
- ♦ Chart Below Uses VERY Rough Approximations

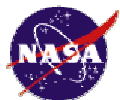
Reorientation Time	Free Space ΔV (Impulsive) Approx. (m/s)	Lambert ΔV (Impulsive) (m/s)	"Lambert" ΔV (Continuous) (m/s)	Best Contin. Accel (m/s ²)	Best Contin. Thrust (N) (750 kg)
3 Weeks	383	415	830	0.46 e-3	0.34
4 Weeks	287	352	704	0.29 e-3	0.22
5 Weeks	230	334	668	0.22 e-3	0.17
6 Weeks	191	335	670	0.19 e-3	0.14





Future Work

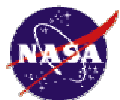
- ◆ Extensive basic orbit design work needed (including low thrust simulations)
- ◆ Alternate mission orbits
- ◆ Ability to meet orbit control requirements (model all significant external forces and their uncertainties)
- ◆ Ability to meet orbit knowledge requirements
- ◆ Effect of orbit drift-away rate (~ 0.1 AU per year)
- ◆ Use of 3 or more spacecraft
- ◆ Consider Putting Both Detector and Lens SC in a Shifted Orbit
- ◆ Effect of decreasing SC separation (less acceleration needed but increased orbit control/knowledge required)
- ◆ Development of Formation Initialization, Station-Keeping, & Re-Orientation Algorithms





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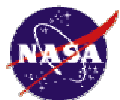
Detailed Information





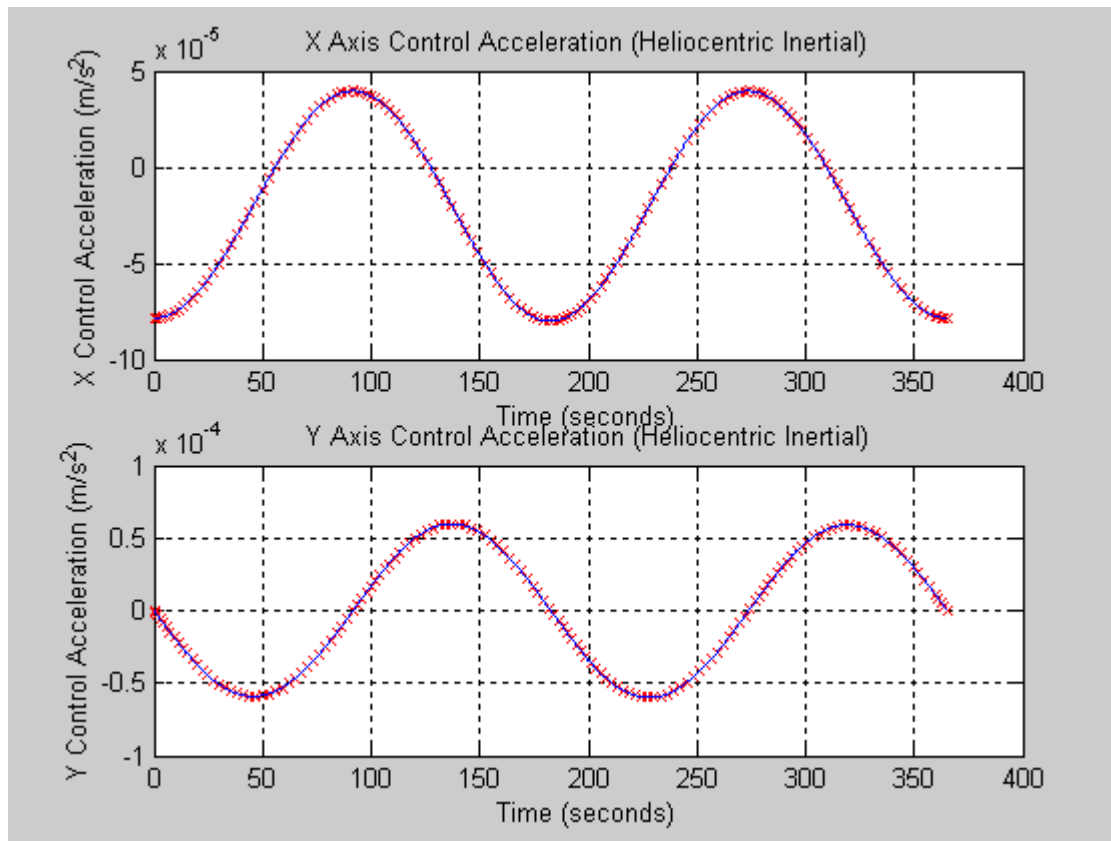
Flight Dynamics Topics

- ◆ Station Keeping Accelerations - Ecliptic Target
- ◆ Additional Trades to Consider - Alternate Mission Orbits
- ◆ Formation Re-Orientation
Free Space Analysis Revisited
- ◆ Additional ΔV Analysis
- ◆ Notes



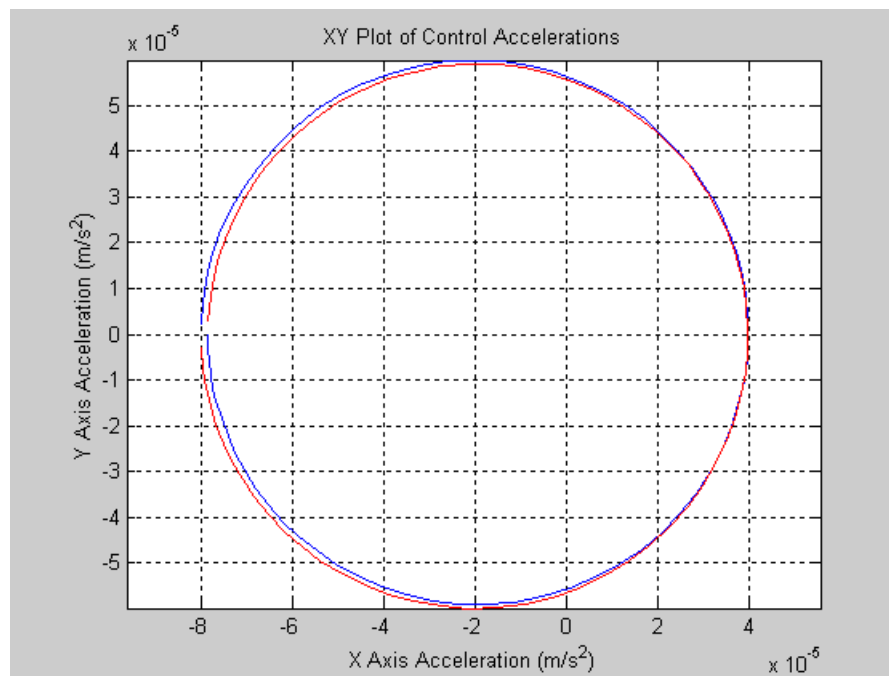


Station Keeping Accelerations - Ecliptic Target (1 of 3)

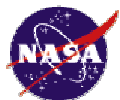




Station Keeping Accelerations - Ecliptic Target (2 of 3)

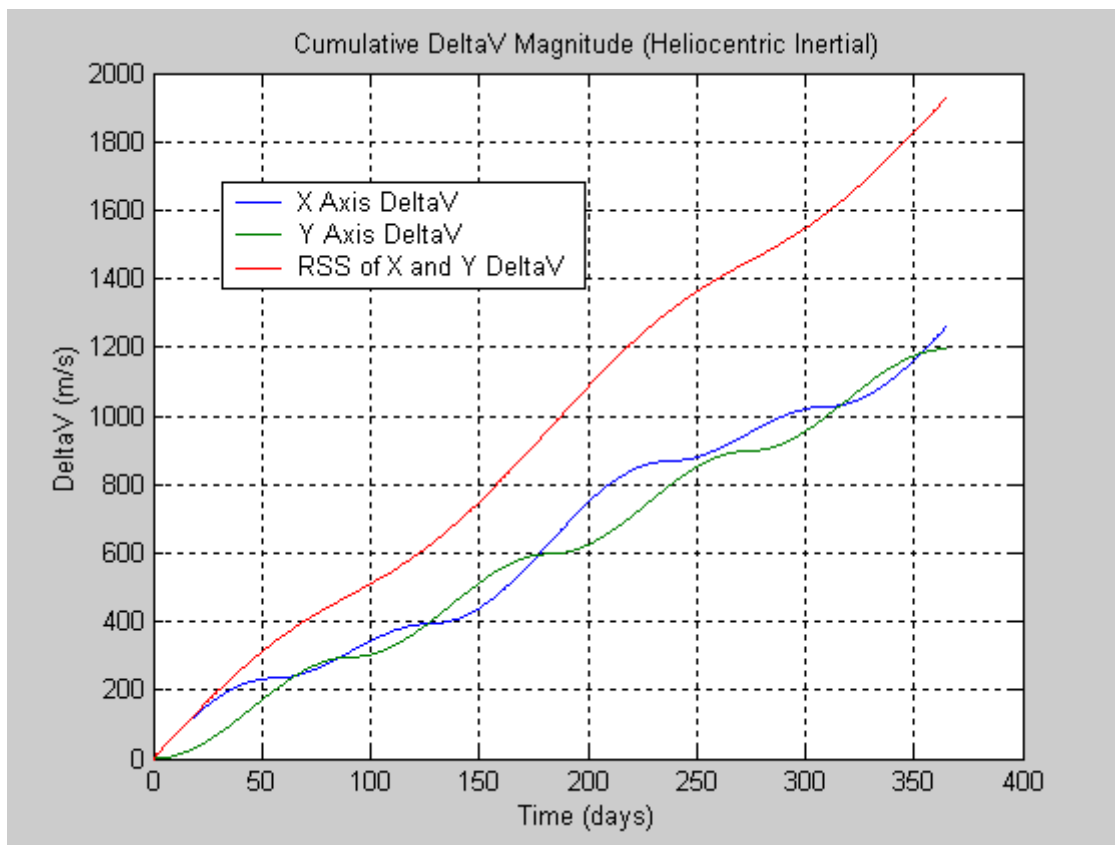


- ◆ XY Plot of Accelerations for 1 Year
- ◆ Acceleration Vector "Rotates" Twice for One Rotation of Earth about Sun (1 Yr)

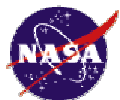




Station Keeping Accelerations - Ecliptic Target (3 of 3)



♦ 2 km/s per Year (Stay on Target All Year)



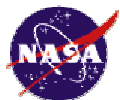


Additional Trades to Consider - Alternate Mission Orbits

♦ Extensive Analysis Required

♦ Possible Alternate Mission Orbits (Credit: Dave Folta)

- Artificial Libration Point-Type Orbit with Solar Sails.
Reference: A. McInnes, Strategies for Solar Sail Mission Design in the Circular Restricted Three-Body Problem, MS Thesis, Purdue University, August 2000.
- Distant Retrograde Orbits.
Reference: O. C. St. Cyr, et. al., Space Weather Diamond: a four spacecraft monitoring system, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 62, No. 14, pp. 1251-1255, (2000).





Formation Re-Orientation Free Space Analysis Revisited

◆ Impulsive Analysis

- One Burn at Observation 1 (Magnitude $V1$) & One Burn (Same Magnitude, Opposite Direction) at Observation 2
- $V1 \text{ (m/s)} = \text{Distance (m)} / t_0 \text{ (s)}$
- Total $\Delta V \text{ (m/s)} = 2 V1 = 2 * \text{Distance (m)} / t_0 \text{ (s)}$ (t_0 is time to re-orient)

◆ Continuous Thrust Analysis

- Acceleration is a positive constant (magnitude A) from $t = 0$ to $t = t_0/2$
- Acceleration is a negative constant (same magnitude) from time $t_0/2$ to time, t_0
- At time, $t=0$ & $t = t_0$, Velocity is 0
- At time, $t= t_0/2$, Velocity reaches a maximum of $V2 = 2 V1 = 2 * \text{Distance} / t_0$
- Total $\Delta V \text{ (m/s)}$ is Twice that of Impulsive Case: $4 * \text{Distance} / t_0$
- $A = \text{Distance} / (t_0/2)^2 = 2 V2 / t_0 = 4 V1 / t_0$





Additional ΔV Analysis

♦ Simulation Parameters

- $C3 = 0.4 \text{ km}^2/\text{s}^2$
- Earth and Solar Gravity Modeled

♦ Formation Initialization (RA=195.7, DEC=-63.8)

- 2 Impulsive maneuvers, 42 days apart, 530 m/s

♦ Target 1 Station-Keeping

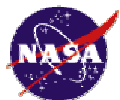
- 43 m/s for 15 days (numerous impulsive maneuvers)

♦ Re-Orientation to Target 2 (RA=195.7, DEC=-43.8)

- 2 Impulsive maneuvers, 7 days apart, 1140 m/s
- 2 Impulsive maneuvers, 21 days apart, 390 m/s

♦ Target 2 Station-Keeping

- 65 m/s for 15 days (numerous impulsive maneuvers)





Notes

- 1) ΔV Numbers Quoted are Magnitudes. "Applied ΔV " Magnitude Will Increase If Thrusters are not Aligned along ΔV Direction
- 2) As Formation Re-Orientation or Formation Initialization time increases, the magnitudes of the 2 Lambert maneuvers become different. Particularly for Formation Initialization, this may increase the magnitude of the Low Thrust acceleration needed.
- 3) Stopping the 0.1 AU/year drift will require propulsion on all SC in the formation.
- 4) A C3 of 0.4 km²/s² Results in a 3 e6 km separation from Earth at approximately L + 30 days.

